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(54) Title: OPTICAL COMMUNICATION SYSTEM USING A HIGH ALTITUDE TETHERED BALLOON
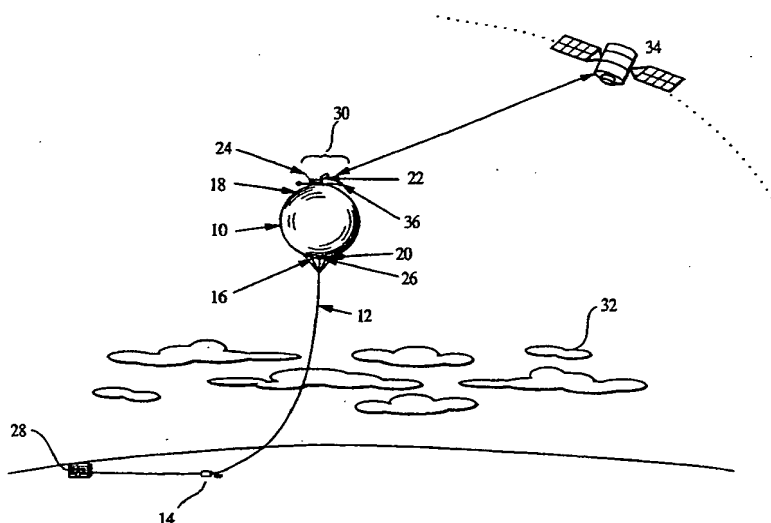
(57) Abstract: An optical communication system using a high altitude tethered balloon (10) that operates above most clouds and atmospheric turbulence. An optical communication system includes a balloon (10) with an optical communication payload (30), a fiber optic cable attached to the tether (12), an automated winch system (14), and a ground station (28). The balloon (10) is designed for sustained flight at, and recovery from, high altitude using the automated winch system (14). An acquisition, tracking and pointing (ATP) system (22) enables a balloon-based optical transceiver (24) to maintain line-of-sight optical communications with an overhead satellite (34). The optical link between the satellite (34) and the balloon (10) is an open channel. Data is transmitted to the ground station (28) from the balloon (10) through the secure fiber optic closed channel attached to the tether (12).

For two-letter codes and other abbreviations, refer to the "Guid-
ance Notes on Codes and Abbreviations" appearing at the begin-
ning of each regular issue of the PCT Gazette.

OPTICAL COMMUNICATION SYSTEM USING A HIGH ALTITUDE TETHERED BALLOON

5   **BACKGROUND OF THE INVENTION**

FIELD OF THE INVENTION

The invention relates generally to an optical communication system using a high
altitude tethered balloon for high data rate communication between ground-based and
10   space-based or high altitude-based instrumentation.

DISCUSSION OF THE RELATED ART

Optical communication systems operate at very high frequencies and are ideally
suited for high bandwidth applications. Compared to radio frequency (RF)
15   communication systems, optical communication systems also generally permit smaller
and lighter system components, require less power, and are more secure. However there
are significant problems associated with the operation of optical communication systems
in the atmosphere. Clouds, rain and fog can scatter optical beam energy and disrupt
communications. Furthermore, turbulence in the atmosphere can distort the optical beam
20   and also cause lost communications.

Many different techniques have been proposed to mitigate problems associated
with atmospheric optical communications. One approach, when communicating from a
ground station to an overhead satellite, is to have several ground stations at different
locations so that a transmission can be sent from the ground station that is least
25   obstructed by clouds. However such an approach likely requires more than three stations,
separated by more than 200 km, to provide a reliable transmission capability. The costs
associated with this approach are prohibitive.

Another approach is to send a repeated packet of data toward a receiver. If a
packet is received during a brief "scintillation window" that results in a clear line-of-sight
30   between the transmitter and the receiver, an acknowledgement is returned to the

transmitter. A subsequent packet of data is then repeatedly broadcast until it is received. However this approach is only able to establish communications through the atmosphere for very brief periods, thus high data rate communications are not optimized.

5   Tethered balloons have been used for generations for long distance communications. Historically the balloons relayed information, often simply visual observations, from one point on the ground to another. Ground-to-aircraft and ground-to-spacecraft RF communications are also relayed using balloons. However viable ground-to-spacecraft optical communications relayed via tethered balloons have not been suggested. Such balloon-relayed optical communications require overcoming both a) the

10   above mentioned problem of atmosphere-induced optical scatter and distortion; and b) the problem of pointing and stabilizing transmitting and receiving optics in turbulent air to achieve the stable narrow beam alignment necessary for modern optical communications.

           To overcome atmosphere induced scatter and distortion of optical signals, another

15   solution is to effectively move above the atmosphere. Free flying high altitude scientific balloons have been used successfully for many years; however, very high altitude tethered balloons operating for extended periods of time in the stratosphere above much of the earth's weather have been generally unsuccessful. Only recently have practical techniques been suggested enabling tethered balloon flights at altitudes near 20 km.

20   **Figure 1** illustrates a typical wind profile and ascent trajectory involved in modulating a tethered balloon through peak jet stream winds to high altitude. During such an ascent maximum tether tension occurs at the balloon-tether interface while the balloon is ascending through the range of peak winds between 8 - 12 km. A thorough understanding of such balloon ascent conditions is necessary to optimize the numerous

25   parameters such as downwind displacement, tether length, free lift, balloon size, and tether and balloon materials.

           Pointing and stabilizing optic communications equipment attached to a balloon is also a difficult technical challenge. At lower altitudes, the wind forces can be so severe that stable alignment of an optical transceiver is not practical.

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In summary, known means of transmitting and receiving high data rate optical communications between ground and space have numerous disadvantages. No solutions have been proposed to efficiently overcome the transmission problems associated with cloud cover and atmospheric disturbances. The advantages however of optical

5   communications are significant compared with other long distance communication methods. The high bandwidth facilitated by optical communications is becoming increasingly important in global communications. Therefore there is a need for an optical communication system that overcomes the above difficulties of optical transmission through the atmosphere.

10

SUMMARY OF THE INVENTION

The present invention, among other things, presents a solution to the aforementioned problems associated with the prior art.

It is an object of the present invention to operate a high altitude tethered balloon

15   that relays optical high data rate communications between space-based and ground-based instrumentation.

A further object of the present invention is to align an optical transceiver attached to a high altitude balloon with an overhead spacecraft.

Yet another object of the present invention is to reduce atmospheric disturbances

20   affecting optical communications between space-based and ground-based instrumentation.

An embodiment of the present invention includes an optical communication system for achieving a clear optical path between earth and space having minimal atmospheric disturbances. The optical communication system includes a high altitude

25   balloon system comprising a balloon, an automated winch near a ground station that is operatively connected to the balloon for launching and recovering the balloon, and a tether extending from the winch to the balloon. The optical communication system further includes a ground station; a transceiver attached to the balloon for transmitting or receiving optical data to and from an overhead spacecraft; an acquisition, tracking and

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pointing system attached to the balloon for locating the spacecraft and for aligning the

transceiver with the spacecraft, thus enabling open channel optical communication

between the balloon and the overhead spacecraft; and a fiber optic cable attached to the

tether and extending from the balloon to the ground station, thus enabling closed channel

5   optical communication between the balloon and the ground station.

The balloon is capable of launch to, recovery from and sustained flight above, for

example, 20 km altitude. At its operating altitude the balloon is above most clouds and

atmospheric turbulence and can establish a clear path of communication with spacecraft

at any altitude and in any orbit. There are several basic orbits used in satellite based

10   communications and reconnaissance. The most common communications orbit is the

Geostationary Earth Orbit (GEO) at altitudes near 36,000 km. The period is equal to the

rotation of the Earth so that the satellite appears to be stationary when viewed from the

ground. Many Low Earth Orbit (LEO) reconnaissance/surveillance satellites are in orbit

at altitudes between 500 to 1,500 km. A resulting orbital period of between 94 to 115

15   minutes allows about 15 minutes of uninterrupted optical data transmission time per

orbit. The optical link between the satellite and the balloon is an open channel. Data is

then transmitted to the ground station from the balloon through the fiber optic cable that

is a secure closed channel. This embodiment makes secure ground to space optical

communications possible by overcoming the problem of cloud cover and atmospheric

20   disturbances and facilitates data transmission rates of more than 2.5 Gigabits per second

(Gbps) bandwidth using current technology.

The present invention therefore provides for high data rate (HDR) optical

communications including applications such as intercontinental satellite communications,

communications to and from deep space, and communications with high altitude based

25   instrumentation, aircraft or missiles.

Other objects and advantages of the invention will become more fully apparent

from the following more detailed description and the appended drawings, wherein the

reference numerals refer to like elements, that illustrate several embodiments of the

invention. In the following description, the terms spacecraft, space-based

instrumentation and satellite are interchangeable and refer to the various devices that may
communicate with the high altitude balloon.

BRIEF DESCRIPTION OF THE DRAWINGS

5   **FIGURE 1** is a graph of a typical wind profile and ascent trajectory involved in
modulating a tethered balloon through peak jet stream winds to high altitude.

FIGURE 2 is a diagram of an embodiment of an optical communication system
using a high altitude tethered balloon according to the present invention.

FIGURE 3 is a diagram of a balloon system according to an embodiment of the
10   present invention.

FIGURE 4 is a cross section of a typical tether used in the present invention.

FIGURE 5A – 5D are graphs showing the "jet-stream related ascent/descent
paradox" associated with the present invention.

FIGURE 6 is a diagram of a pressurization system according to an embodiment
15   of the present invention.

FIGURE 7 is a diagram of a fuel generated power system that can be used in the
present invention.

FIGURE 8 is a diagram of a solar energy Regenerative Fuel Cell (RFC) power
and storage system that can be used in the present invention.

20   **FIGURE 9** is a chart illustrating information flow during a data downlink from
space to a tethered balloon according to an embodiment of the present invention.

FIGURE 10 is a chart illustrating information flow during a data uplink from a
tethered balloon to space according to an embodiment of the present invention.

25   ## DETAILED DESCRIPTION OF THE INVENTION

Figure 2 is a diagram of an embodiment of an optical communication system
using a high altitude tethered balloon according to the present invention. The system
includes a spherical balloon **10** attached by a tether **12** to an automated winch **14** located
on the ground. A pressurization system **16** is used to maintain the differential pressure

between the balloon's internal gas and the ambient atmosphere. Power for a payload 30 and the pressurization system 16 is supplied by solar array cells 18 in combination with fuel cells 20 for energy storage. The payload 30, mounted on the balloon, includes an Acquisition, Pointing and Tracking (ATP) system 22 that provides accurate position and

5   attitude information for target tracking, and other communications equipment. Targets may include but are not limited to various space-based instrumentation 34 such as satellites, spacecraft in deep space, and high altitude airplanes and missiles. Also included in the payload are Global Positioning System (GPS) antennas 36 for determining the position and attitude of the balloon 10 in earth fixed coordinates. Optical

10   data is communicated to and from an open channel transceiver 24 attached to the balloon 10 and aimed toward space. Open channel communication between the balloon 10 and the space-based instrumentation occurs above most clouds 32 and above most atmospheric turbulence. A fiber optic transceiver 26 attached to the balloon enables optical communications with a ground station 28 via a fiber optic cable attached to the

15   tether 12.

Figure 3 is a diagram of a balloon system that can be used in the invention. Although various balloon shapes may be used, in this embodiment the balloon 10 is a spherically shaped, constant volume balloon with a ballonet 50 (a variable volume internal air compartment known in the art). The ballonet 50 allows the balloon 10 to

20   maintain constant positive pressure throughout the entire operating regime, thus permitting the balloon's overall volume and external shape to remain nearly constant. At low altitudes, the majority of the balloon's external volume is occupied by air inside of the ballonet 50. The air in the ballonet 50 is vented during ascent, such that at higher altitudes the majority of the balloon's external volume is occupied by the helium chamber

25   52. Similarly, during balloon descent, the pressurization system 16 forces air into the ballonet 50 to maintain the balloon's 10 constant pressure and external shape.

A spherically shaped balloon is used in this embodiment because it has advantages over an aerostat (an aerodynamically shaped balloon) in that the former has the highest volume-to-surface area and the lowest skin stress-to-volume ratio of any

shape. This allows the flexible structure to be fabricated with not only less material, but also very light materials. Because the balloon **10** is capable of operating at very high altitudes above most atmospheric turbulence, the balloon **10** presents a relatively stable platform for aligning optical equipment with the spacecraft **34** and enabling free space

5   (open channel) optical communication between the balloon **10** and the spacecraft **34**.

Figure 4 depicts the cross-section of a typical tether **12** that can be used in the present invention. For example, a center strand **60** is surrounded by four filler strands **62**. Optical fibers **64** and power conducting wire may be embedded in the filler strands **62**. Encircling the filler strands **62** is a braided strength member **66**. Finally, an optional

10   lightning protection braid **68** is covered by an outer thin insulation jacket **70**.

The tether **12** serves two purposes: as a structural link between the balloon **10** and the winch system **14** on the ground, and as an optical link between the balloon **10** and the ground station **28**. The tether **12** can be configured, for example, as a circular cross section with a slight taper from the balloon **10** to the ground. The tether **12** is sized based

15   on peak tether tension that occurs at the balloon-tether interface while the balloon **10** is ascending or descending through the altitudes with the highest wind speeds, generally well below the operational altitude of the balloon **10** according to the invention.

In order to effectively be above most clouds and atmospheric turbulence, the balloon **10** operates at altitudes approximately between 12 and 21 km. These altitudes

20   could require a corresponding tether length up to 25 km. At such length, the associated weight of the tether **12** significantly affects the design of the balloon system. New advanced materials are recommended for the tether **12** because of their excellent strength-to-weight capability. One such material is a thermoplastic, multifilament yarn, melt-spun from liquid crystal polymer that is manufactured by Hoechst Celanese under the

25   trademark VECTRAN.

As illustrated in **Figure 1**, because the balloon volume is strongly dependent on the tether weight, which is a function of the required tether strength, the entire balloon system is sized respectively to a maximum dynamic pressure condition in the wind profile.

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First, the tether strength and diameter are determined. The analysis assumes a balloon of a given size is flying at an altitude corresponding to the maximum dynamic pressure in the wind profile. Knowing the aerodynamic characteristics of the balloon 10, in particular the drag coefficient, balloon size, and windspeed, the peak tether tension of

5   the balloon 10 is computed. Combining the peak tether tension with certain tether design parameters such as diameter and weight as a function of break strength, the tether diameter required to cope with the maximum tether tension of the balloon 10 is computed taking into consideration a margin of safety for the tether 12.

Next, at successive increments of altitude decreasing from an altitude

10   corresponding to the maximum dynamic pressure in the wind profile, the tether angle with respect to the vertical is computed, taking into consideration aerodynamic characteristics of the tether increment, its weight, and the local windspeed. This process is continued until the tether reaches the ground or the tether angle equals 90 degrees at some altitude, in which case the tether profile becomes horizontal. This method is used

15   iteratively until a balloon and tether size are identified which result in a computation continuing to the ground with the tether angle slightly less than 90 degrees.

The automated winch 14 pays out and retrieves the tether 12, facilitating the deployment and recovery of the balloon 10. Successful recovery of the balloon 10 is an important feature of the system due to the cost of the balloon 10 and payload 30

20   components. An automatic winch 14 facilitates the tether 12 outhaul and inhaul modulation required during the ascent and descent phases of the flight. If during the descent of a balloon 10 the descent rate exceeds the capability of the pressurization system 16, the balloon 10 will become flaccid and the drag will increase, potentially raising the tether tension beyond allowable limits.

25   If, during the descent phase of flight, there is not enough lift to maintain tether tension as the balloon 10 enters the high wind regime (the jet-stream), the balloon 10 may be forced into an uncontrolled descent. One solution is to modulate the tether 12 speed during the descent. Actively controlling the in-haul and out-haul speed of the tether 12 can be very effective at controlling the balloon's vertical descent rate within the design

envelope. As illustrated in **Figure 5**, this solution leads to a phenomenon called the "jetstream related ascent/descent paradox". For example, in order to continue a controlled descent the tether direction must be reversed (paid out) and the speed modulated in such a way that the balloon **10** continues descending within the

5   pressurization system **16** design limits.

Figures **5A-5D** illustrate the need for tether modulation during the descent (recovery) phase of the balloon system. First, consider for example the case of a 170,000 cubic meter balloon being in-hauled through the mean wind-altitude profile that is shown in **Figure 1**. Referring to **Figure 5A**, as the tether length is reduced from the operational

10   altitude at point A, the balloon **10** finds new equilibrium positions between points A and B, matching the steady state equilibrium solution. However, further reduction in the tether length from position B results in a new equilibrium position at point C, at a significantly lower altitude below point B. From point C to the ground at point D, once again there is an equilibrium position corresponding to each incremental tether length

15   reduction. Between points B and C, there is no equilibrium position that also satisfies the tether length constraint. Equilibrium can only be obtained if the tether length is greater than at point B, requiring out-haul of the tether **12**. Out-hauling and in-hauling of the tether **12** (modulation) could result in the balloon following a trajectory similar to the steady state solution, as shown in **Figure 5B**, depending on the modulation speed profile.

20   However, if the tether **12** is in-hauled at a constant speed of 1 m/s, then during the critical B-C phase, there is a large decrease in tether length, resulting in the balloon's **10** vertical descent speed peaking at 6.4 m/sec, as shown in **Figure 5C**. The resulting significant amount of air required beyond the capabilities of the pressurization system **16** could lead to a catastrophic failure. With the tether modulation, however, a tether in-haul/out-haul

25   speed range of +/- 1.5 m/s is sufficient to regulate the balloon's **10** vertical descent speed to less than 1.2 m/s during the critical phase of the flight (**Figure 5C**). The corresponding required pressurization profile of the balloon **10**, shown in **Figure 5D**, is well within the capabilities of a reasonably sized pressurization system.

Figure 6 is a diagram of one type of pressurization system 16 that can be employed in the present invention. Ambient air is pumped into the ballonet 50 by a fan 82 driven by an electric motor 84, thus modulating the size of the helium chamber 52. The size of the pressurization system 16 is dependent on the size of the balloon 10, ΔP, the operational environment (temperature and windspeed variation) and the balloon's 10 descent rate during in-haul.

Successful operation of the invention requires the pressurization system 16 to maintain the differential pressure (ΔP) between the balloon's internal gas and the ambient atmosphere such that the balloon 10 will be rigid enough to retain a spherical shape and limit aerodynamic drag so that the resulting tether tensions are acceptable. At the same time, the balloon material must not be overstressed by excessive pressurization. Prior aerostat experience, also applicable here, has shown that a ΔP of approximately 250 N/m^2 is satisfactory. The pressurization system 16 is also required to mitigate changes in ΔP due to diurnal variations in atmospheric temperature.

Figure 7 shows an example of a fuel generated power system that can be employed in the present invention. There are numerous suitable fuel cell systems that are commercially available. The power system in Figure 7 uses hydrogen 90 and oxygen 92 as reactants. Mixing the two in a fuel cell 96 produces power that is conditioned before being supplied to the pressurization system fan motor 84 and/or to the payload 30.

A power system is required to support the payload 30, pressurization system 16, and other electrical components of the invention. Of these, payload and pressurization require an order of magnitude greater power than the other components' functions. Historically, low altitude tethered aerostats have used powered tethers: electric power transmitted from the ground to the aerostat via a copper wire in the tether 12. However, at high altitude the weight of a powered tether could make the present invention non-feasible.

Figure 8 shows an example of a solar energy Regenerative Fuel Cell (RFC) power and storage system that can also be employed in the present invention. AeroVironment developed such a system in collaboration with NASA-Glen. The

expected specific energy density of an RFC of 600 W-hr/kg, is three times that of a
current state-of-the-art Lithium/Polymer battery storage system. During the day, with a
water electrolyzer 102, some of the solar energy from solar array 18 is used to generate
hydrogen 104 and oxygen 106 that is then stored for night use with fuel cell 108. The
5   solar energy system, directly or indirectly, is used to power the pressurization system 16
and the payload 30.

Figure 9 is a chart illustrating information flow during a data downlink from
space to the balloon 10 according to an embodiment of the present invention. The
payload 30 includes the Acquisition, Tracking and Pointing (ATP) system 22, and other
10   communications equipment such as the fiber optic transmitter terminal 26 at the balloon-
end of the tether 12.

The operation of the payload 30 is as follows. First, consider the case in which a
satellite 34 is the source of the optical communications signal that is received by the
transceiver 24 on the balloon 10, the so-called downlink case. Mounted on the balloon
15   10 is a differential GPS (Global Positioning System) receiving system 110 which
includes multiple GPS receiving antennas 36 and a differential GPS processor. The
antennas 36 are mounted as far apart as possible as the balloon size permits enabling the
differential GPS system 110 to determine the coarse attitude information 112 of the
balloon 10 relative to earth fixed coordinates. Also mounted to the balloon 10 is a GPS
20   navigation receiver 114 which provides determination of the balloon 10 position in earth
fixed coordinates. Combining the position of the balloon 10 and the time with the
attitude information enables the attitude of the balloon 10 to be determined in inertial
coordinates. The satellite ephemeris 116 is determined by any of a number of standard
methods, and it provides information about satellite position in inertial coordinates. By
25   differencing satellite position and balloon position, the coarse line of sight 118 from the
balloon 10 to the satellite 34 is determined in inertial coordinates. Combining the line of
sight and the balloon attitude, a balloon body centered pointing direction is determined
and this is used as a coarse pointing control 120 for a gimbal 122. The gimbal 122 points
a telescope 124 towards the satellite 34 whereupon the telescope 124 receives within its

field of view the optical signal source **126** on the satellite **34**. An optical system consisting of the telescope **124** and its associated optics has a field of view adequate to receive the optical signal source **126** from the satellite **34** when the telescope **124** is coarsly pointed towards it. The optical components include a high bandwidth transceiver

5   **24** that has a field of view narrower than that of the telescope **124**. It is necessary to achieve fine pointing of the high bandwidth transceiver **24** towards the satellite signal source **126**. This is achieved by a fine pointing system that includes a focal plane array **130** that images the signal source **126** and an image processor **132** that locates the signal source **126** within the field of view of the telescope **124** and determines a change in the

10   pointing direction of the telescope **124** so as to center the signal source **126** within the narrow field of view of the high bandwidth transceiver **24**. This pointing difference is used to generate a fine pointing control signal **134** that is used to steer the gimbal **122** finely so the optical signal from the satellite **126** is received by the optical transceiver **24**. Alternatively, a different type of fine pointing system can be used as long as it has the

15   capability of centering the signal source to place it within the field of view of the high bandwidth optical transceiver **24**. Finally, to complete the data downlink from space to the ground station **28**, the optical transceiver **24** is operatively connected to the fiber optic transmitter terminal **26** at the balloon-end of the tether **12**. Data is then transmitted to the ground station **28** through the optical fibers **64** embedded in the tether **12**.

20   An alternative to the above procedure would be to carry out all calculations in earth fixed coordinates. Thus, rather than first compute the line of sight to a satellite in inertial coordinates and then convert this to balloon body coordinates, the calculation could be done in earth fixed coordinates and then directly converted to balloon centered coordinates.

25   FIGURE 10 is a chart illustrating information flow during a data uplink from the balloon **10** to space according to an embodiment of the present invention. The signal source is the transceiver **24** on the balloon **10** and the signal receiver **142** is on the satellite **34**. In this case it is also necessary to have an optical beacon **144** on the satellite **34** to allow fine pointing of the signal at the satellite **34**. The operation is similar to the

downlink case, explained with respect to **Figure 9**, in that the GPS receivers **110** and **114** and satellite ephemeris **116** are used to achieve coarse pointing of the gimbal **122** controlling the telescope **124**. In this case, however, there is no signal coming from the satellite **34**. Instead an optical beacon on the satellite **144** provides an optical signal that

5   is used by the focal plane array **130** and image processor **132** to achieve fine pointing control **134** of the gimbal **122**. The optical signal from the transceiver **24** on the balloon **10** is passed through the telescope **124** to project it towards the receiver **142** on the satellite **34**.

It is also possible that a combined uplink/downlink system can be constructed. In

10 this case, the fine pointing is achieved as with the downlink system shown in **Figure 9**. Once the pointing is achieved, the telescope **124** is used to transmit the optical signal from the balloon **10** to a satellite **34** with no additional pointing needed.

In summary, the present invention provides for high data rate (HDR) optical communications between ground-based and space-based or high altitude-based

15 instrumentation. While the above description contains many specifics, the reader should not construe these as limitations on the scope of the invention, but merely as examples of specific embodiments thereof. Those skilled in the art will envision many other possible variations that are within its scope. For example, supplying power to the payload **30** could be accomplished by other means such as long-life batteries. Accordingly, the

20 reader is requested to determine the scope of the invention by the appended claims and their legal equivalents, and not by the specific embodiments given above.

CLAIMS

1   1.   An optical communication system for achieving a clear optical path between earth

2   and a spacecraft with minimal atmospheric disturbances, comprising:

3   a ground station;

4   a high altitude balloon system, said balloon system including:

5   a balloon;

6   an automated winch near said ground station and operatively connected to

7   said balloon for launching and recovering said balloon; and

8   a tether extending from said winch to said balloon;

9   a transceiver attached to said balloon for transmitting or receiving optical data to

10   and from the spacecraft;

11   an acquisition, tracking and pointing system attached to said balloon for locating

12   the spacecraft and for aligning said transceiver with the spacecraft, enabling open channel

13   optical communication between said balloon and the spacecraft; and

14   a fiber optic cable attached to said tether and extending from said balloon to said

15   ground station, enabling closed channel optical communication between said balloon and

16   said ground station.

1   2.   An optical communication system as recited in claim 1, wherein said fiber optic

2   cable is embedded in said tether.

1   3.   An optical communication system as recited in claim 1, wherein said tether is

2   tapered between said balloon and said winch.

1   4.   An optical communication system as recited in claim 1, wherein said balloon is

2   spherical in shape.

1   5.   An optical communication system as recited in claim 1, wherein said balloon is

2   operated at altitudes approximately between 12 and 21 km.

1   6.   An optical communication system as recited in claim 1, wherein said high altitude

2   balloon system further comprises:

3   a ballonet; and

4   a pressurization system, operatively connected to said ballonet, for filling and

5   exhausting said ballonet.

1   7.   An optical communication system as recited in claim 1, wherein the spacecraft is

2   a satellite.

1   8.   An optical communication system as recited in claim 7, wherein said acquisition,

2   tracking and pointing system comprises;

3   a telescope;

4   means for determining a coarse line of sight from said balloon to the satellite;

5   and

6   a gimbal, operatively connected to said telescope and to said means for

7   determining said coarse line of sight, for aligning said telescope with said coarse line of

8   sight from said balloon to the satellite.

1   9.   An optical communication system as recited in claim 8, wherein said acquisition,

2   tracking and pointing system further comprises a differential GPS system for determining

3   a coarse attitude of said balloon relative to earth fixed coordinates.

1   10.   An optical communication system for achieving a clear optical path between earth
2   and a spacecraft with minimal atmospheric disturbances, comprising:
3   a ground station;
4   a high altitude tethered balloon operatively connected to said ground station;
5   means, operatively connected to said balloon, for transmitting optical data
6   between said balloon and the spacecraft;
7   means, operatively connected to said balloon, for aligning said means for
8   transmitting optical data between said balloon and the spacecraft; and
9   means, operatively connected to said balloon and said ground station, for
10   transmitting optical data between said balloon and said ground station.

FIG. 1

MAX TETHER TENSION

BALLOON-TETHER ASCENT TRAJECTORY

MAX TETHER TENSION

BALLOON-TETHER ON-STATION PROFILE

ALTITUDE (km)

20

12

6

0

0   15   30
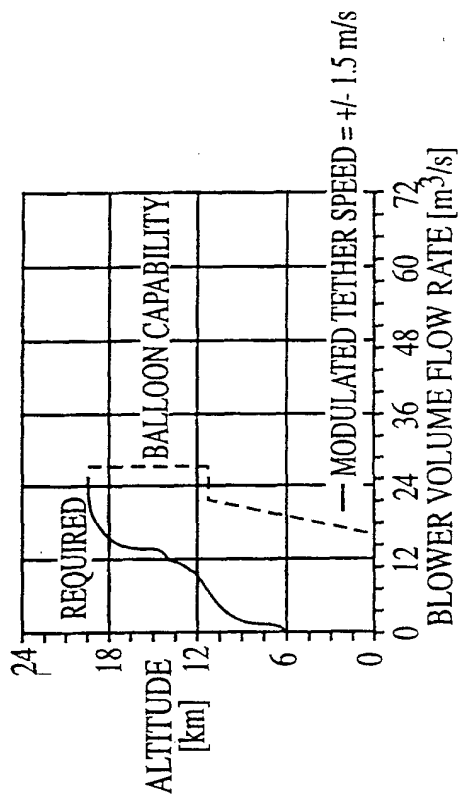
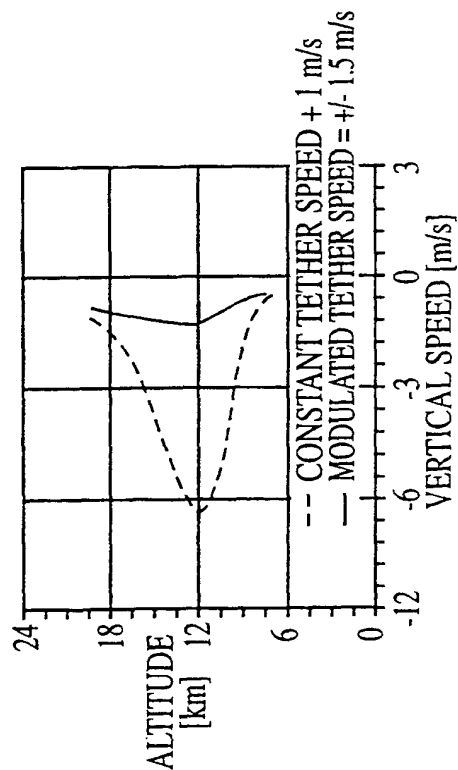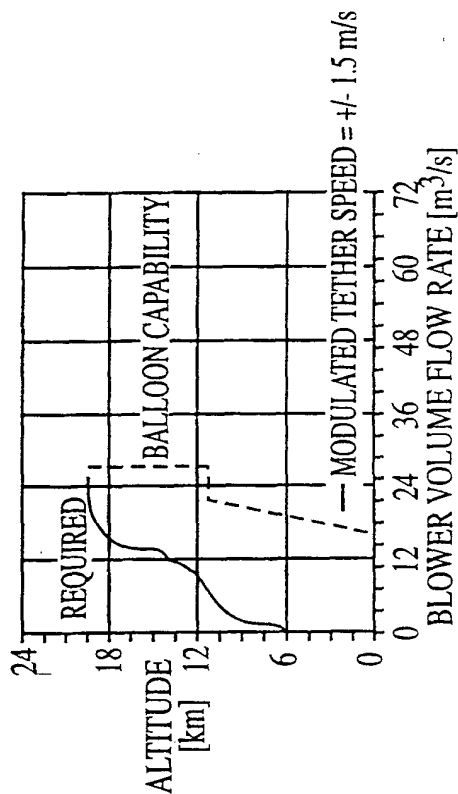WIND SPEED (m/s)

TYPICAL WIND PROFILE

FIG. 2

FIG. 3

FIG. 4

FIG. 5B

FIG. 5D

FIG. 5A

FIG. 5C
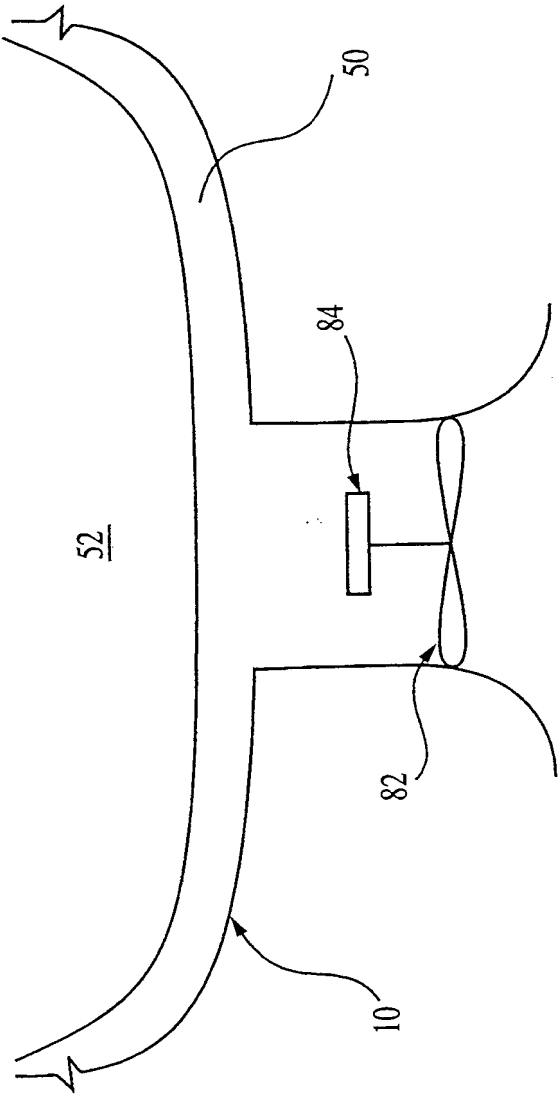
FIG. 6

7/9
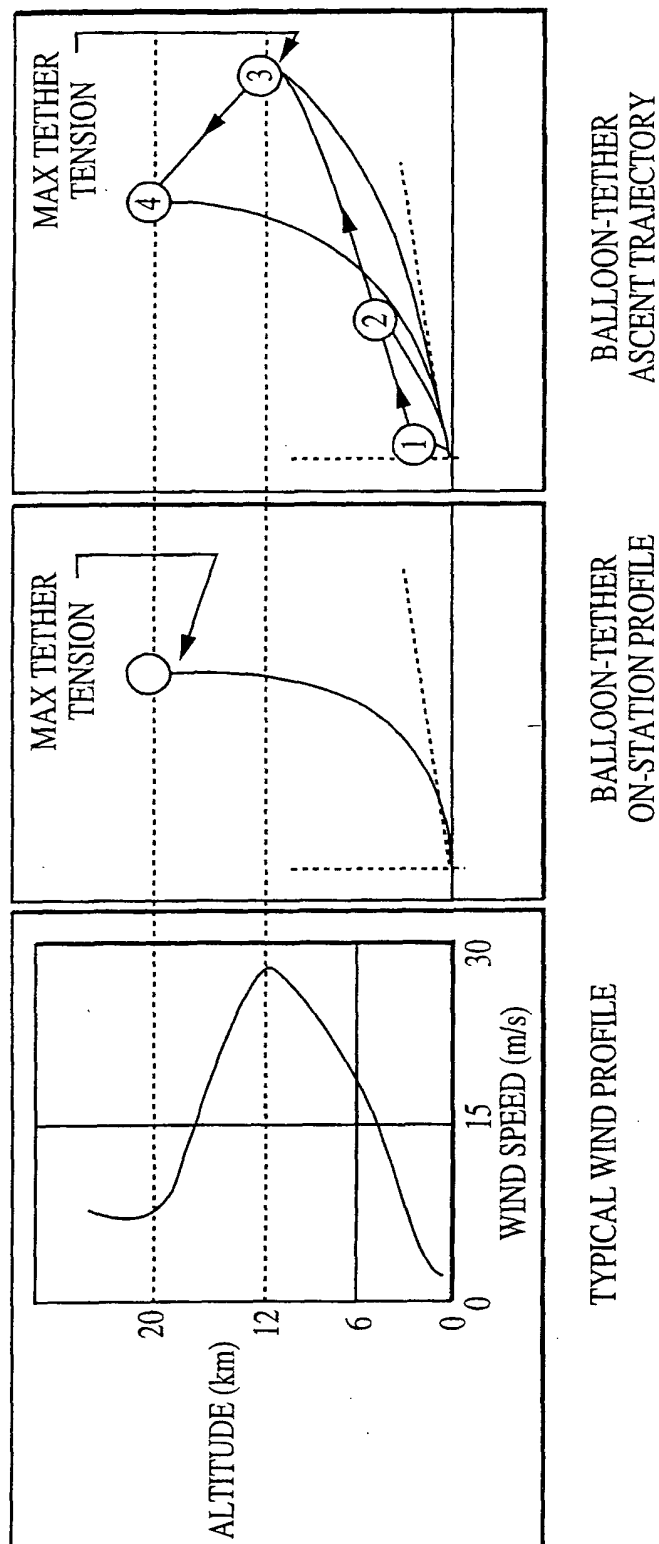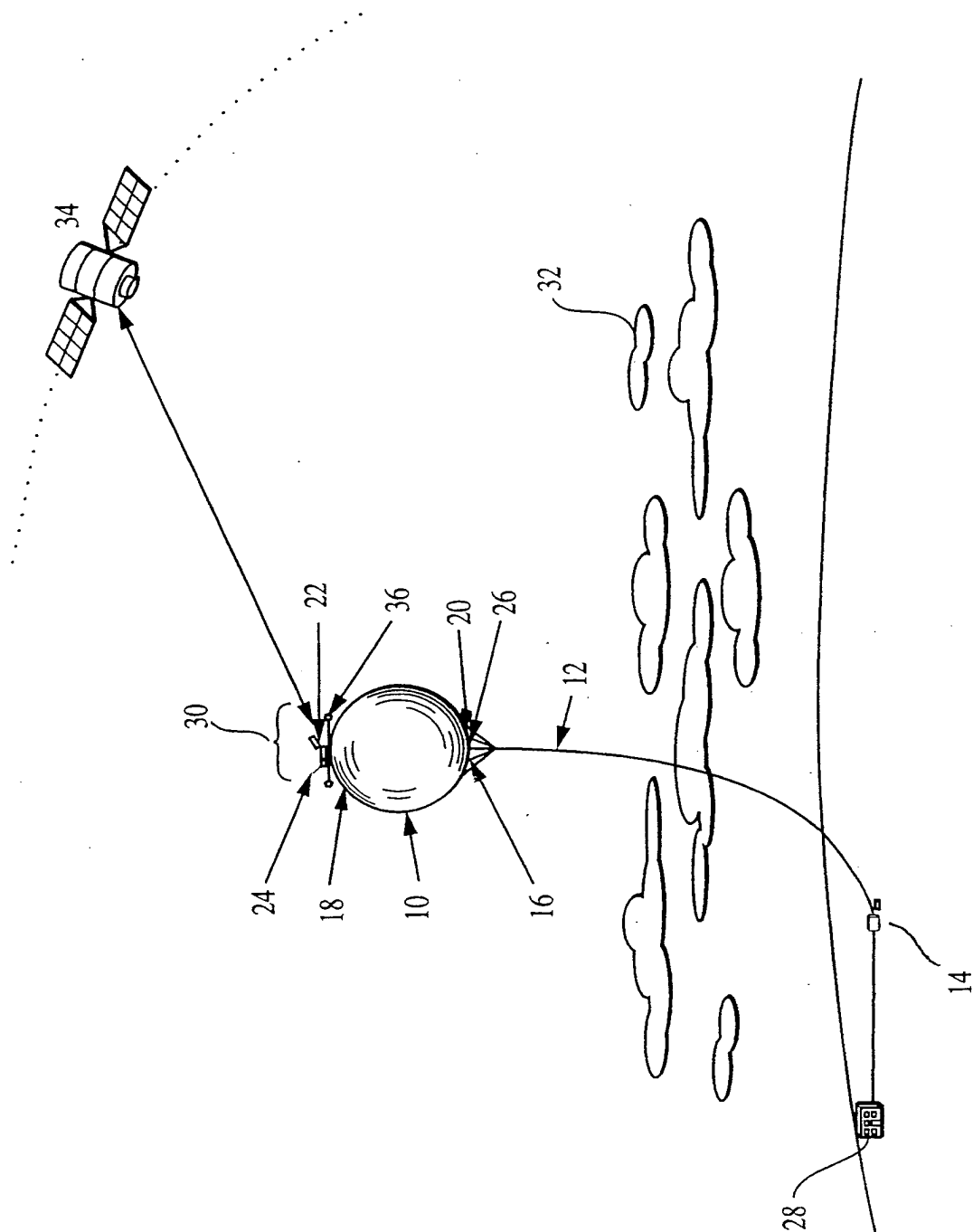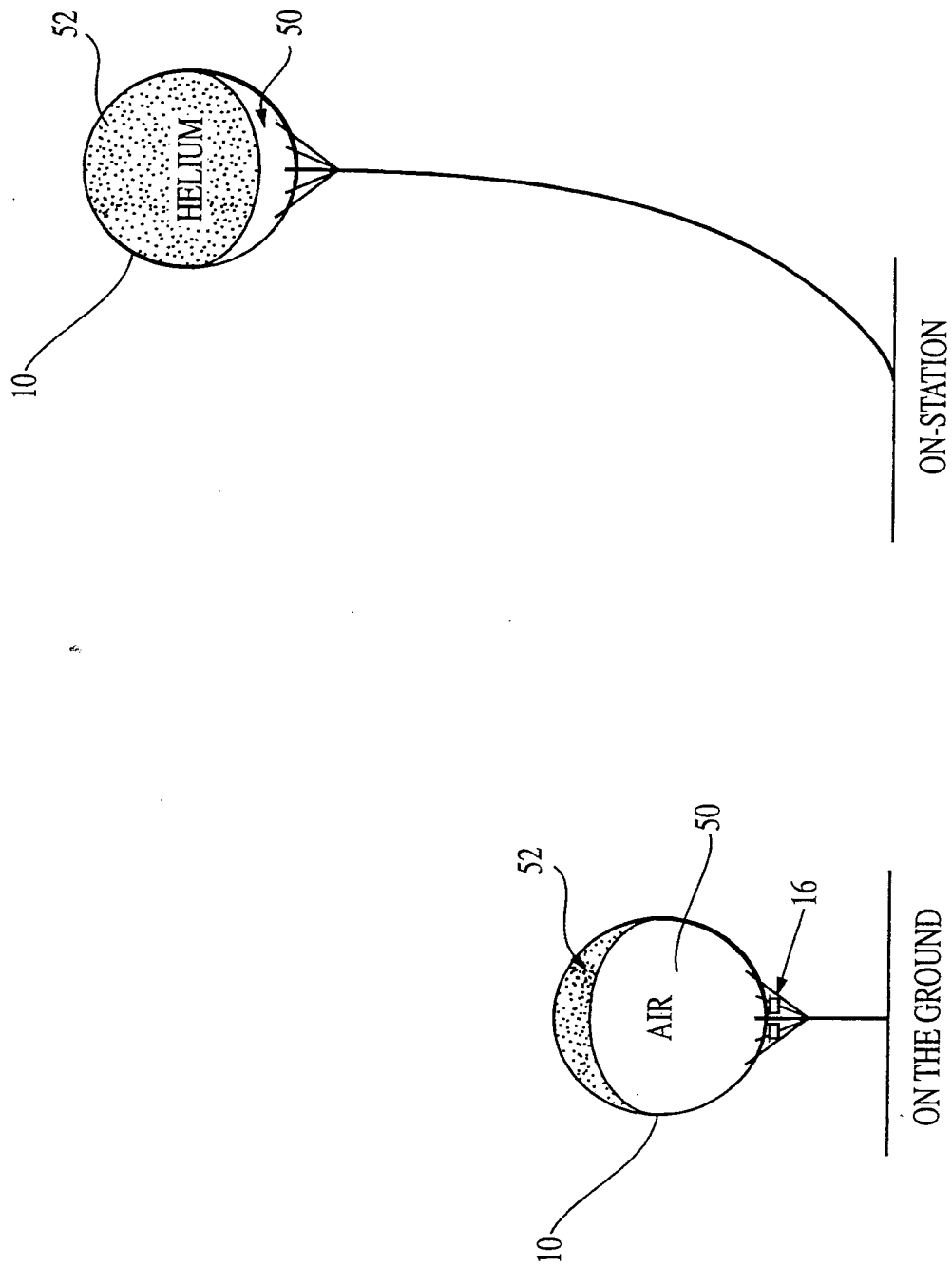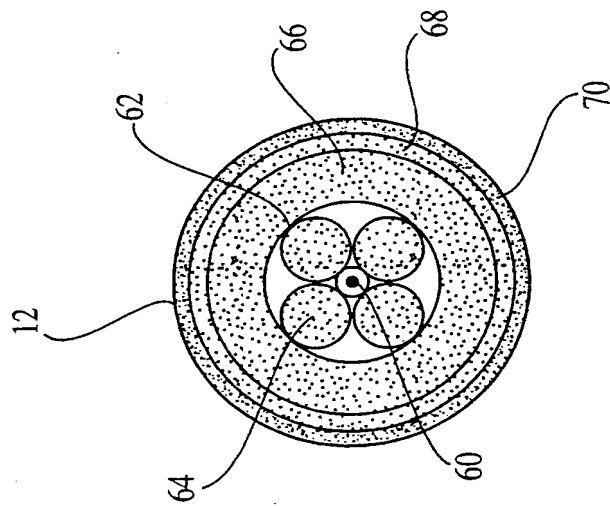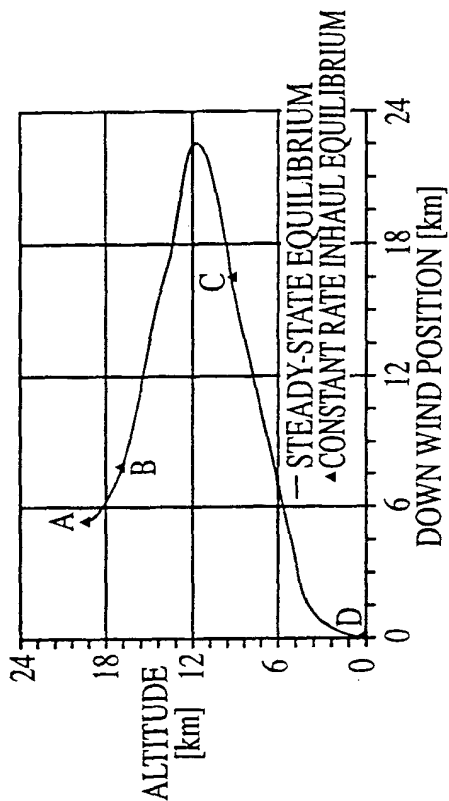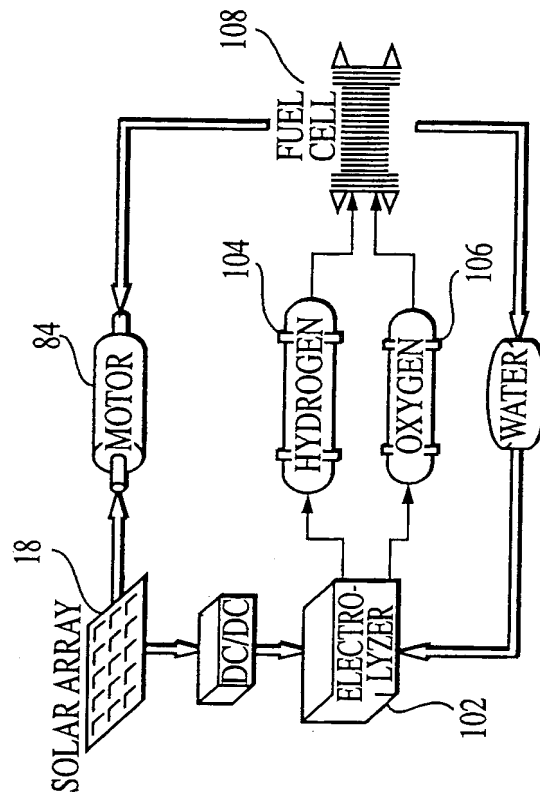
FIG. 8

FIG. 7
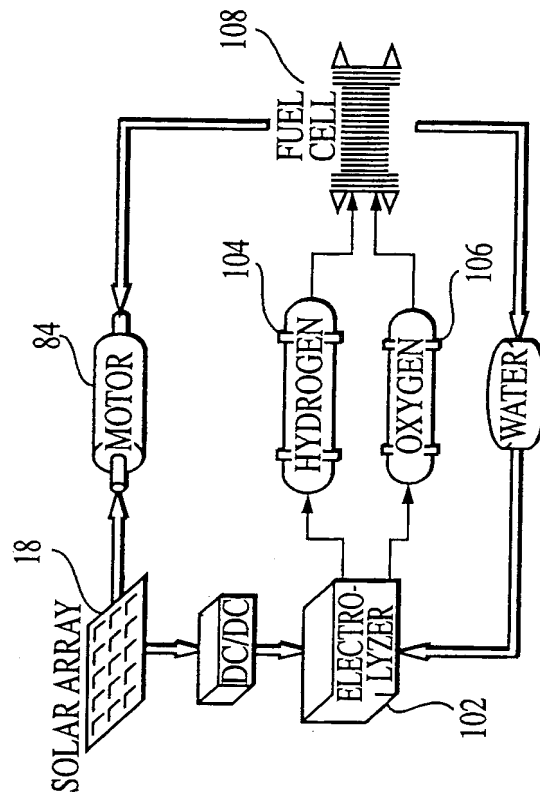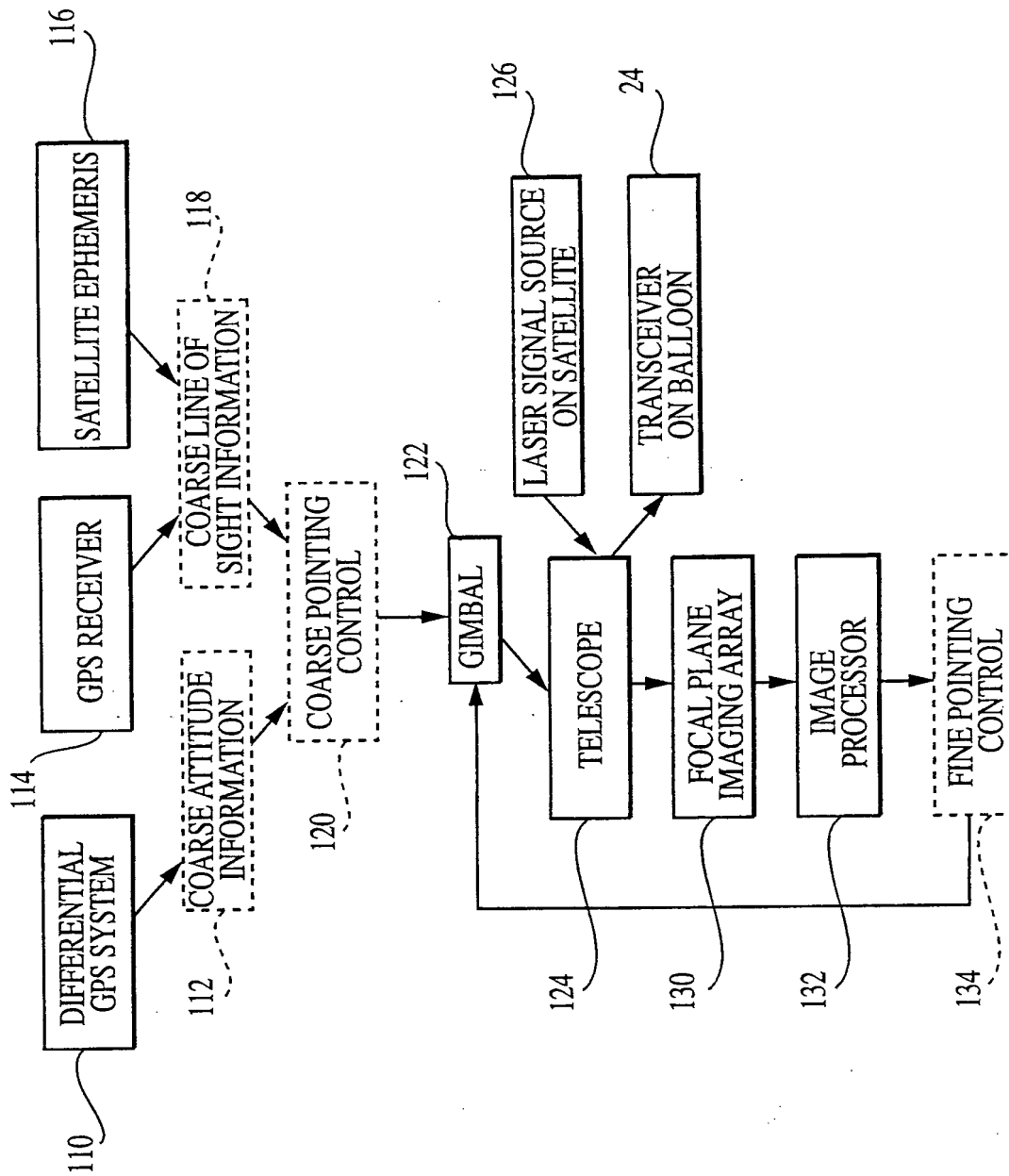
FIG. 9
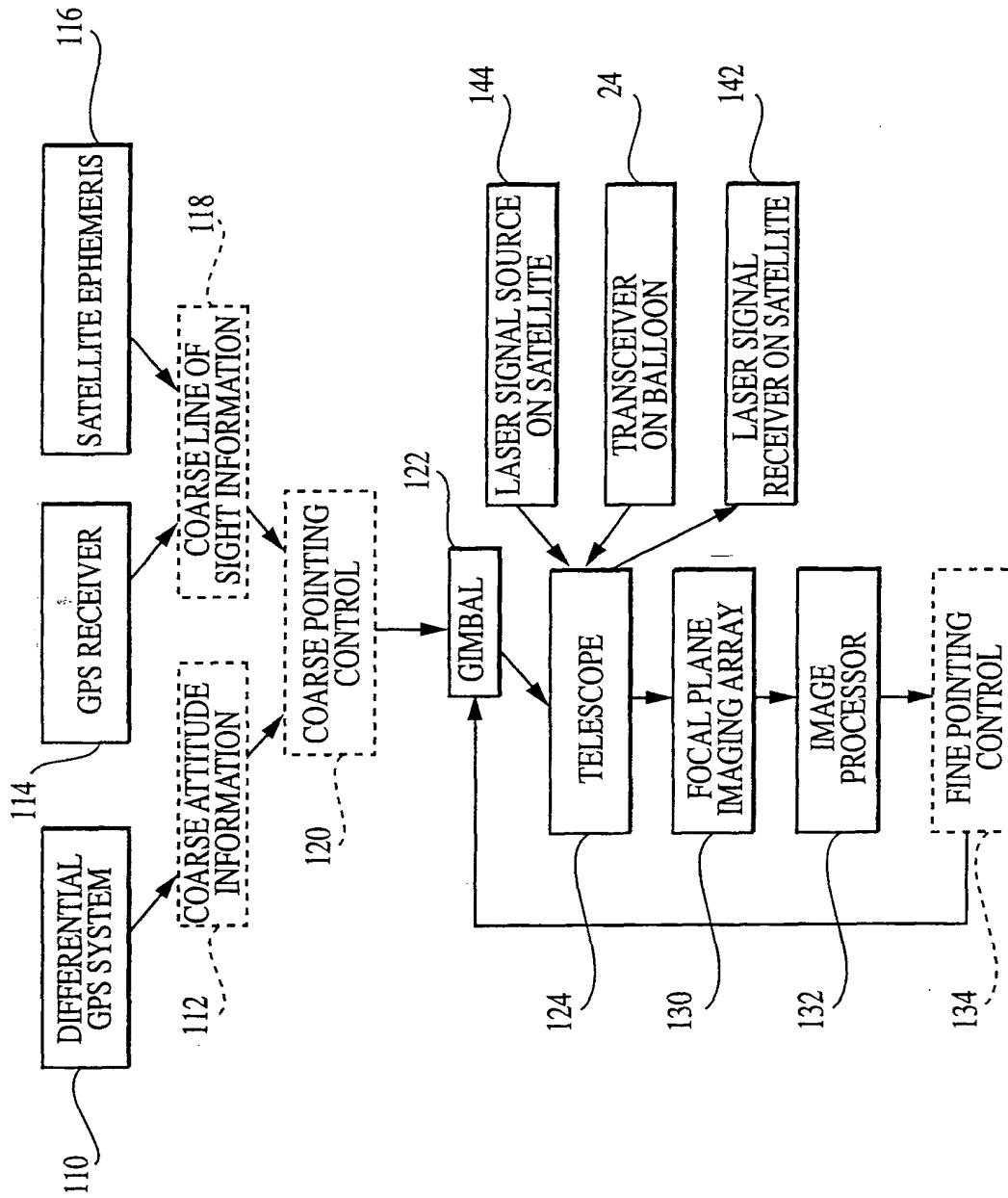
FIG. 10

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04B10/105   B64B1/50   B64G1/66

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H04B   B64B   B64G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 909 299 A (SHELDON JR L PHILIP ET AL) 1 June 1999 (1999-06-01)	1,2,4,5, 7,10
Y	column 11, line 51 -column 12, line 64 claims 19,20,22	3,6,8
Y	US 6 010 093 A (PAULSON ALLEN E) 4 January 2000 (2000-01-04)	3
A	column 2, line 17 - line 47 column 5, line 1 - line 8 column 7, line 1 - line 12	9
A	US 4 842 221 A (BEACH GLENN R ET AL) 27 June 1989 (1989-06-27) column 1, line 1 - line 30 column 2, line 51 -column 3, line 17 column 3, line 38 - line 43 figures 1-3	1-3,6

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| X | Further documents are listed in the continuation of box C. | | X | Patent family members are listed in annex. |

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'A' document defining the general state of the art which is not considered to be of particular relevance

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'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

'&' document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 May 2001	28/05/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Carrasco Comes, N

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INTERNATIONAL SEARCH REPORT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4 995 572 A (PIASECKI FRANK N) 26 February 1991 (1991-02-26)	6
A	column 4, line 66 -column 5, line 23 column 7, line 7 - line 26 column 8, line 2 - line 7 ---	2,3
Y	US 5 390 040 A (MAYEUX ERIC J) 14 February 1995 (1995-02-14) column 2, line 64 -column 3, line 13 column 4, line 1 - line 11 -----	8

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

2

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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US 6010093	A	04-01-2000	NONE		
US 4842221	A	27-06-1989	NONE		
US 4995572	A	26-02-1991	NONE		
US 5390040	A	14-02-1995	NONE		